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MECHANICAL CHARACTERIZATION OF LASER SURFACE ALLOYED ZINC ON ALUMINIUM

MOERA GUTU JIRU[1*], BHASKARAN J[2] & RAJENDRAN R[3]

[1,2]Assistant professor, Mechanical Engineering, Adama Science and Technology University, Ethiopia

[3]Professor, Centre for Automotive Materials, SRMIST, Chennai, India

ABSTRACT

Laser surface alloying of commercial pure aluminium with alloying elements finds application in automobile and aerospace industry. Mechanical characterisation study necessitates to understand the micro structural modification and mechanical behaviour on thin film of coated alloy to know the stability in terms of wear and corrosion characteristics. In this study, aluminium was coated with zinc using continous wave CO_2 laser power. After alloying, it was observed that there is an improvement in hardness and scratch resistance because of the formation of intermetallics. The effect of laser energy density on surface hardness was investigated. The coefficient of friction was less for AlZn alloy and it was decreasing with increased scratch load from 20-70 N. The formation of refined grain structure and sound metallurgical alloying, the microstructure had contributed for surface scratch damage resistance.

KEYWORDS: Laser Surface Alloying, Surfacer Hardness, Scratch Testing, Aluminium & Zinc Alloy

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Original Article

1. INTRODUCTION

Failure of an engineering component is due to poor metallurgical alloying, poor design, poor material selection and reaction with external environment. Non-ferrous metals and alloys such as copper, aluminium, magnesium and titanium have high demands in engineering applications. Aluminium alloys has received high attention among non ferrous metals because of its high specific strength to weight ratio, resistance to corrosion, excellent thermal properties, workability and recyclability. One of the major drawbacks of aluminium is its poor wear resistance, can be improved by surface modification [1]. One such technique is laser surface alloying. Various investigators have carried out research on laser surface alloying on aluminium. It has been reported that the micro hardness of pure aluminium can be enhanced from 26 to 54 H_V, due to Fe-Ni alloy formation[2,3] and reported that TiO_2 slurry spray coating has improved the adhesion strength of mild steel and the strength was increased with sintering temperature ranging from 850°C–950°C. Mabhali [4] noticed that laser alloying of aluminium AA1200 with 30 wt.%Ni and 70wt.% SiC improves hardness up to 104.8$H_{V0.1}$ and When on 70wt.% Ni, hardness was increased to 120.7$H_{V0.1}$.

Nwambu [5]noticed mechanical alloying of commercial aluminium with 7.2 wt.% and Co improved its hardness up to 234 HV. While alloying with 7.2 wt.% Mo, the hardness increased to 222 HV with its impact energy of 1.87J. Thomas [6] carried out abrasion wear study on alumina ceramic using surface scratch test for evaluation of third body wear damage by different materials of Co-Cr and alumina ceramic. Their result indicated that surface scratch resistance was higher than substrate material. Gee [7] carried out low load multiple scratch test on ceramics and hard metals and concluded that the width of scratches in ceramics were higher than most hard metals. The build up of gross damage was more for coarse grain than fine grain materials. Vencl[8] conducted the wear, scratch study

on ferrous-based coatings, and observed that the coefficient of friction and wear depend on hardness and wear mechanism of materials. Yuan [9] studied the scratch test for the evaluation of abrasion wear of aluminium matrix composite reinforced with in-situ AlB_2. Progressive nominal loading from 0.1–30 N with scratch length of 3 mm employed to evaluate the wear resistance, which improved due to AlB_2 particles. Ravi [10] reported laser surface alloyed aluminium alloy Ni and Cr metal powders using CO_2 laser powers from 1.0, 1.5 and 2 kW. Maximum hardness achieved by using 1.5kW power with was 700 HV for 20 wt. % Ni, 80 wt.% Cr. Low laser power has no significant alloy formation while using high power create more depth of alloy which result in less hardness. Zinc alloyed coating enhances the corrosion resistance for complex shaped lightweight automobile pars [11]. Further chromated coating stabilizes the zinc and prevent from white rust corrosion.

2. MATERIALS AND METHODS

An aluminium plate of size 60 x 30 x 10 mm3 was used in this study. The chemical composition is 0.1 wt.% Cu, 0.6 wt.% Si, and 0.3 wt.% Fe and remaining aluminium as parent material. For alloying, pure zinc powder of 99.8% purity was mixed with chemical binder (fevigum-commercial brand name) and coated uniformly on aluminium with thickness of 0.35mm. Coated samples allowed curing at room temperature for two days. Laser exposed to the surface for melting both the coated zinc powder and substrate material at 1.6–2.0 kW power as mentioned in table1. Metallographic studies imposed after fine polishing of alloyed samples along thickness direction to identify the surface morphology. After etching with standard Keller's reagents (1ml HF, 1.5ml HCl, 2.5ml HNO_3 and 95 ml of distilled water), both optical microscopy and Field Effect Scanning Electron Microscopy (FESEM) were used to study microstructure. On the surface, elemental analysis performed using Electron X-ray Dispersive Spectroscopy (EDS). Vickers hardness testing machine with 0.3kg load was used for measuring micro-hardness in thickness direction. In order to obtain the laser energy density (E) the following standard formula given by:

$$E = \frac{\mathrm{P}}{\mathrm{Vd}}, \tag{1}$$

Where, 'p' laser power in J/s, V is laser beam speed in mm/s and'd' is laser beam diameter mm.

Table 1: Process Parameters used for Laser Alloying

Laser Power (W)	Scan Speed (mm/min)	Laser Beam Diameter (mm)	Laser Specific Energy (J/mm^2)
2000	600	7.40	27
1900	500	7.40	31
1800	400	7.40	37
1700	300	7.40	46
1600	200	7.40	65

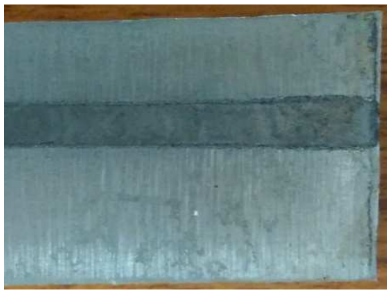
Surface scratch test using TR-101 machine with diamond indenter estimate the wear resistant of alloyed surface. Variation in scratch loads from 10 to 70 N tested at constant load with 0.2 mm/s and offset distance of 1 mm and stroke length was 5 mm. Before scratch testing, initial surface roughness of sample was measured using non-contact optical surface profile-meter. The observed average surface roughness (R_a) after laser beam alloying was 0.62µm. The size of the scratch damage, measured using noncontact profile-meter and scratch aspect ratio calculated from wear scar damage.

3. RESULTS AND DISCUSSION

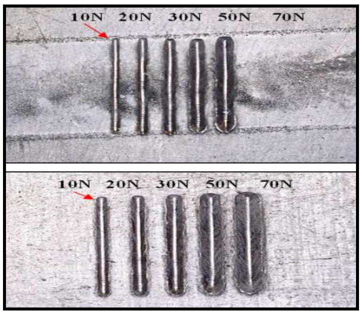
3 1: Microstructure and Surface Morphology

Figure 1(a) shows the zinc powder coated on the aluminium substrate. The coating is sound and uniform with good adherence to the substrate material. Figure 1(b) shows the distinct and uniform alloy region after laser beam surface alloying. Figure 1(c) shows the surface damage after scratch test. It seems to be narrow due to the improved hardness. The cross-section of laser-alloyed sample in figure 1(d) indicates the width and depth.

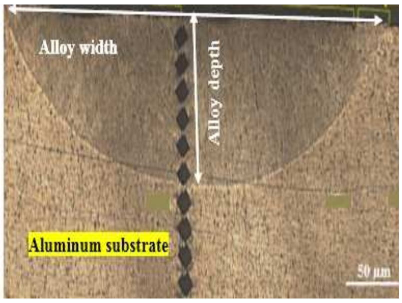
(a) Aluminium Substrate Coated with Zinc



(b) After Laser Surface Alloying



(c) Surface Damage After the Scratch Test



(d) Cross-Section of Alloy Zone.

Figure 1: Photographs of Laser Surface Alloyed Aluminium Samples Processed at 27 J/mm^2 Laser Energy Density

The morphology of Al-Zn alloy was studied using Field Emission Scanning Electron Microscope (FESEM) images is shown in Figure 2(a, b). The white patches represent aluminium grains and the black portions zinc grains in micro structure analysis using Scanning Electron Microscope (SEM). Formation of new intermetallics compounds in the alloy has enhanced the hardness and thereby improved wear resistance property. A typical microstructure of aluminium-zinc alloy formed by laser surface alloying by 31J/mm^2 laser energy density is shown in Figures 2(a-d). Between the alloy and substrate interface, there is no metallurgical defects formed ensuring a good alloy has been maintained. Due to controlled heat input and less heat affected zone by laser surface alloying; those metallurgical defects were solved. Fast solidification of melting region resulted in the formation of fine dendritic microstructure like the one shown in Figure 2(b). Inter-diffusion of zinc with aluminium resulted in formation of dendrite microstructure in the upper and middle of alloy zone (Figure 2c). Solubility of zinc in liquid aluminium resulted in the formation of different grain structures at interface and top alloy zone. The microstructure with refined grains without micro cracks in the interface despite of variation in melting temperature good metallurgical alloying was obtained.

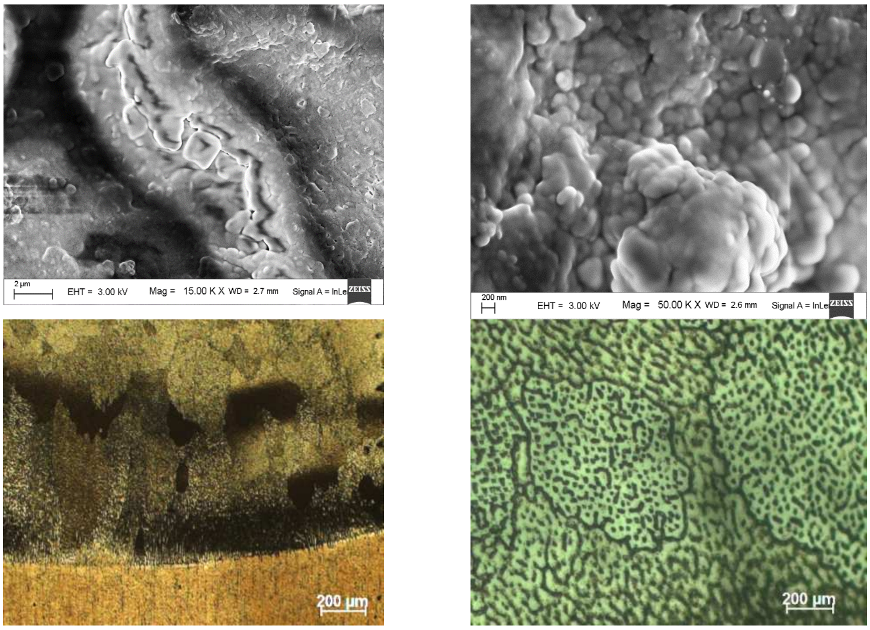


Figure 2: Micrograph of Alloy Sample Processed using 31 J/mm^2 : (a, b) Surface Morphology of AlZn Alloy Region; (c) Interface Region of Alloy Zone and (d) Alloyed Region at Center.

The interface zone has thick layer of very closely packed planar grain sizes was found as shown in Figure 2(c). Above the interface zone, grain structures are grown in the direction of solidification as a result, the upper portion has fine net works of dendrite structures (Figure 2d). It is obvious that dendrite microstructure cannot be formed with pure metals and mechanical alloying, it is difficult to get dendrite microstructure without managing solidification rate to be higher by quenching methods. The advantage of laser surface alloying is high solidification rates enhanced by substrate region acting as heat sink. Laser interaction time with workpiece must be shorter to achieve faster solidification rate. Table 2 shows EDS result after laser beam alloying aluminium with zinc. Zinc atoms are randomly distributed in aluminium in the form of round shapes which can be seen in figure 3. Maximum concentration of 21.7 wt. % Zn and 20.1wt.% Zn were revealed. The variations of zinc at different locations; less as 2.5 wt.% Zn and 2.7 wt.% Zn were due to diffusion process where upper portions have more alloying elements than near interface regions. It is obvious that element zinc has hexagonal close packed crystal structure with melting point of nearly 419.5 °C temperature. It is near to that of aluminium which is 650°C. John [1] studied the reaction of zinc at temperature of 380°C in liquid solubility as much as 95 wt. % Zn. However, solid solubility is less to 66.4 wt. % Zn which is greater than any element miscibility with aluminium in solid solubility.

Table 2: Chemical Composition in wt. % of Al-Zn Alloy

Spectrum	Zn	C	O	Si	Cu	Mg	Fe	Al
14	8.0	25.2	31.0	0.2	0.1	0.1	0.1	35.4
15	7.7	36.5	11.2	0.4	1.3	-	0.4	42.6
16	2.5	16.7	5.8	0.1	-	-	-	74.9
17	21.7	-	2.4	0.1	0.3	0.1	4.2	71.2
18	2.7	17.4	50.7	0.2	-	-	0.2	28.8
19	6.5	25.7	39.2	3.7	-	0.2	0.2	24.1
20	20.1	6.4	8.5	0.1	-	-	0.3	64.6
21	9.7	9.6	12.8	0.1	0.1	0.1	0.6	67.0

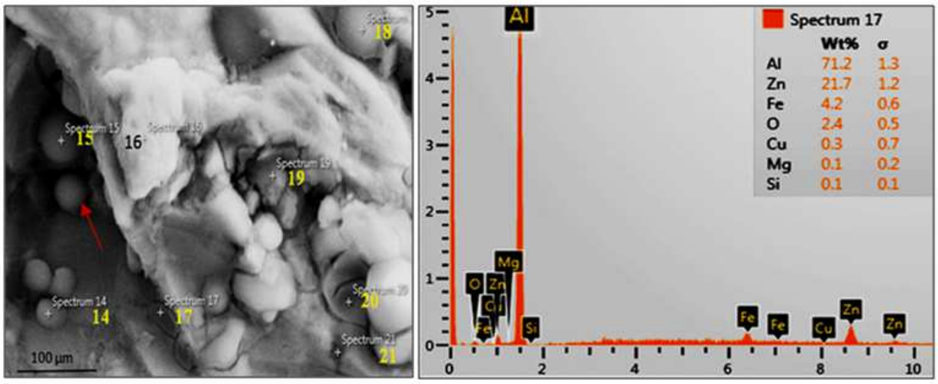


Figure 3: EDS Image and Point Spectrum of Al-Zn using 31J/MM²Laser Beam Energy.

3.2 Micro hardness and Laser Alloy Geometry

Micro hardness of laser surface alloyed materials deposited at different laser energy density were tabulated in Figure 4. For Al-Zn alloy, average of 50.76 $H_{V0.3}$ hardness achieved when laser energy density is 27 J/mm^2. When laser beam energy density is increased, its hardness continuously decreased and minimum for 37 J/mm^2. Hardness decreases from top alloy zone towards substrate material. Since high energy create more depth where the concentration of alloying elements are less. When compared with substrate material, which is 28 HV $_{0.3}$, there is an improvement by 44.8%.

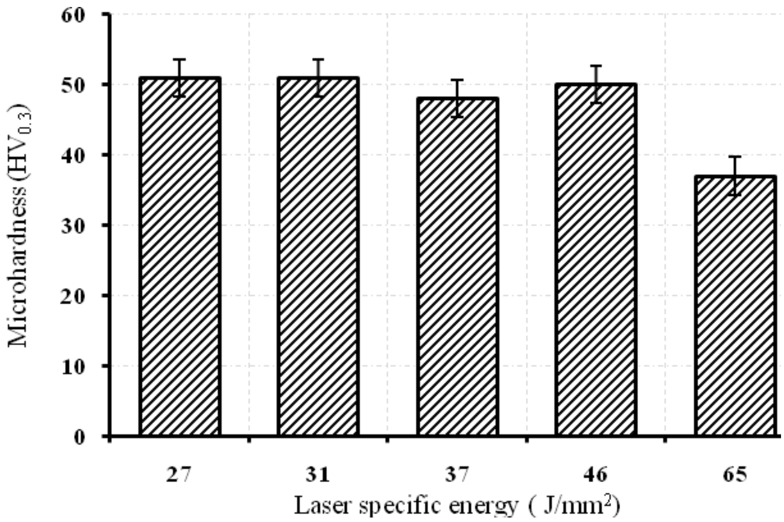


Figure 4: Effect of Laser Energy Density on Micro-Hardness.

3.3 Analysis of Surface Scratch Test

Figure 5 shows comparison of scratch surface-damage width for substrate material and aluminium zinc alloy. The laser alloying had less surface damage due to improved mechanical interlocking which lead to increase in the hardness. The figure 5 shows the effect of laser energy density on surface damage zone in the experimental investigation. There is a linear increased damage zone when laser beam energy from 27 to 65 J/mm^2. Maximum scratch width of 330.9µm and 405.32 µm observed for pure aluminium, when 10N and 20N loads, respectively. Figure 6 (a, b) confirmed that the 2D profile of surface damage zone for Al-Zn alloy and pure aluminium, respectively. Figure 6 illustrates that lesser surface damage found in Al-Zn alloy than pure Aluminium. Figure 7 (a, b) demonstrates Three-dimensional profile (3D) of scratch grooves intensity and the variations clearly observed in the graph, where more deformation build up was visible in Figure 9(b), for

aluminium. The depth of damage zone measured as 100µm and 86 µm, for unalloyed aluminium and Al-Zn alloy, respectively.

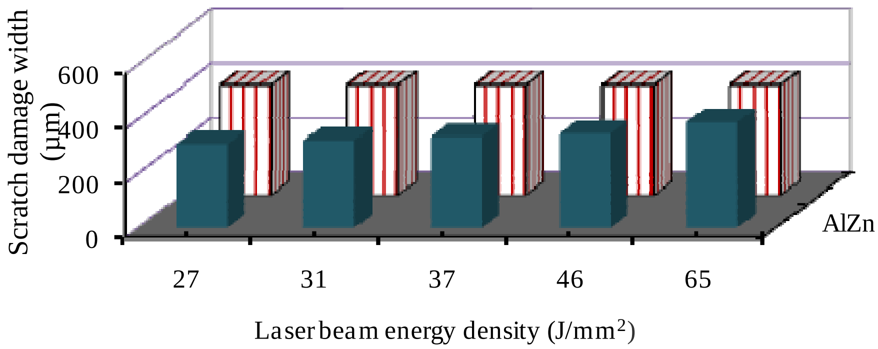


Figure 5: Effect of Laser Energy Density on Abrasion Wear Width for different Materials at 20N Load

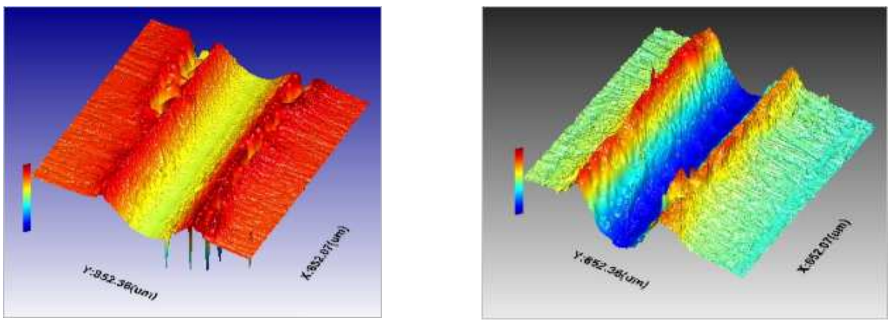


Figure 6: Scratch Groove Profile when 20N Load and 27 J/mm² (a) Al-Zn Alloy and (b) Pure Aluminium

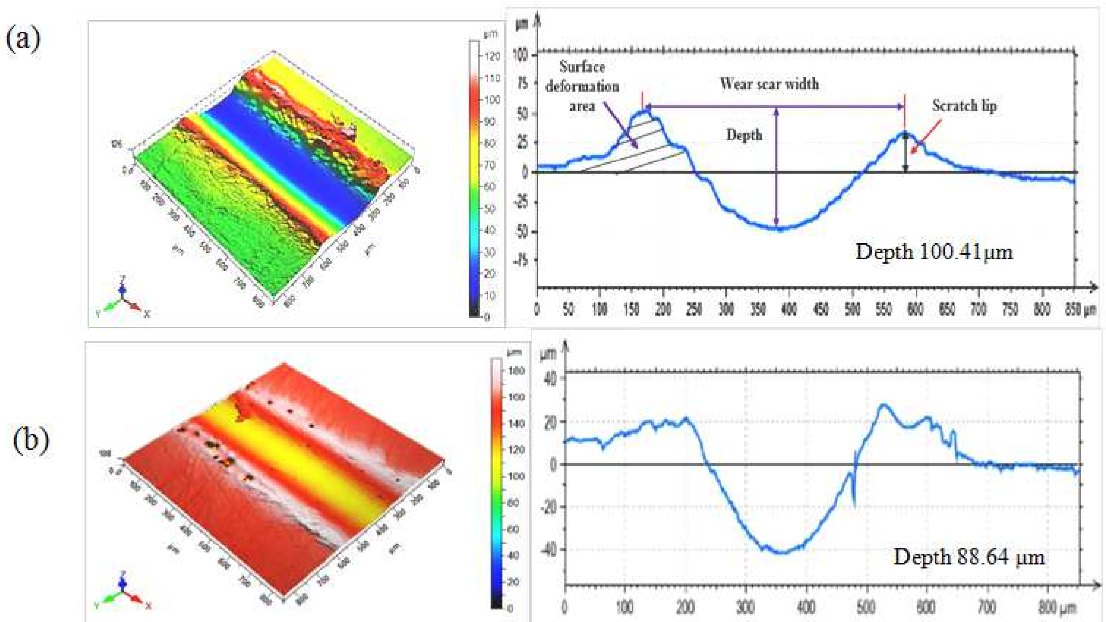


Figure 7: Three-Dimensional Image and two-Dimensional Wear Scare Profile for 20N Load (a) Pure Aluminium, (b) Al-Zn Alloy

3.4 Coefficient of Friction

The effect of laser energy density on coefficient of friction studied for Al-Zn alloy and pure aluminium compared in subsequent analysis. The comparison study made for all samples processed at 31J/mm^2 laser energy density. The minimum value of co-efficient of friction observed for 31J/mm^2, which has 0.481 at 20N and 0.349 at 70N load. When laser energy density is 37J/mm^2, has 0.53 and 0.403, respectively for 20N and 70N loads. In general, when laser energy density is increased the average coefficient of friction, the values also increased but reduced with load for all samples processed by different laser energy density. For selected laser energy density of 31 J/mm^2, online coefficient of friction as a function of scratch length was shown in Figure 8(a, b). The initial raise in the profile is due to static coefficient of friction and soon the stability maintained with little variation in the kinetic coefficient of friction conditions. Maximum load of 70 N has minimum values of coefficient of friction. In general, for Al-Zn alloy coefficient of friction was less due to improved surface hardness.

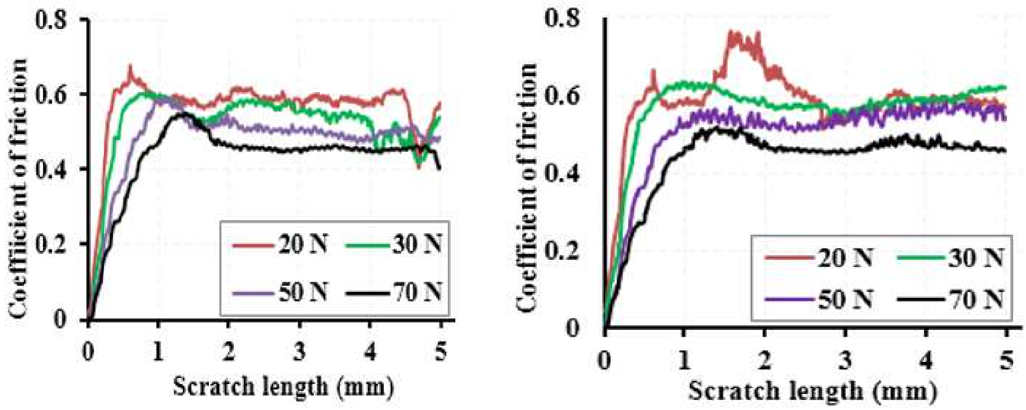


Figure 8: The Online Coefficient of Friction for Samples Processed by 31 J/mm^{2}as Energy Density (a) Al-Zn and (b) Pure Aluminium.

4. CONCLUSIONS

Surface performance after laser beam alloying of pure aluminium with zinc metal powder was successfully completed. These are main findings of this research work:

- Metallurgical properties like inter metallic compound, microstructure of alloy region was very sound, without defects such as micro cracks, porosity and grain boundary formation.
- Surface hardness has improvement by 45% and surface scratch deformation resistance was improved.
- The effect of laser beam energy density improved the hardness of surface as well scratch surface damage resistant.

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AUTHOR'S PROFILE

Dr. Moera Gutu J. is Assistant professor in the Department of Mechanical Engineering (Design and Manufacturing Engineering program). He has graduated in B. Sc. in Manufacturing Technology from Adama University in 2006. In the same University he has graduated in M.Sc. in Manufacturing Engineering in 2010.

Dr. Moera Gutu J. after he has changed officially his name from Dr. Woldentinsay Gutu Jiru, has done his Ph.D. in Indian Institute of Technology in 2018 in Mechanical Engineering.

He has graduated by Advising 3 MSc. students and currently advising four Ph.D. students and four M.sc. students. Dr. Moera Gutu is currently working in Adama Science and Technology university on the position of associate dean for postgraduates.

He has published more than 10 research articles and 8 international conferences and one book chapter. His area of research is surface engineering, advanced micromachining and corrosion science.

Dr. J. Bhaskaran is working as Assistant Professor in Mechanical Engineering (Design and Manufacturing Program) at Adama Science and Technology University, Adama, Ethiopia. He had completed his Ph D. (Process monitoring of hard

turning using acoustic emission technique) [at prestigious national Laboratory, Central Manufacturing Technology Institute CMTI, Bangalore] in Mechanical Engineering (Anna University) and published research articles with more than 30 Citations in reputed and Scopus indexed International Journal. Also hehave been recognized as a Research supervisor for M.S and Ph D by Anna University, Chennai, INDIA. I had also 1½ year Industrial experience as Production Engineer/ Design Engineer apart from 25 years of teaching experience at various levels (Professor/ Associate professor/ Assistant professor) in reputed Institution/University in INDIA and abroad. Not only in academic, he took training/technical classes for Industrial executives to renowned companies like L&T, Ford India Ltd, Apollo tyresetc in his carrier.

Dr.R.Rajendran is currently working as **Professor** in the department of Automobile Engineering at SRM Institute of Science and Technology, Chennai, India. He is also heading the Centre for Automotive Materials. He has been involved in teaching for the past **25** years. He has adopted Observe and Discover methodology in his teaching and published papers related to teaching in Materials Education Symposium, UK. He has conducted research on development of new material for piston ring sponsored by IP Rings Limited for his PhD work. He was a visiting researcher at Queens University, UK under the International Travel Grant Scheme from Royal Society London Jan-Mar 2010. He has worked on **ITER project**(International collaborative project to demonstrate sustained fusion reaction in a reactor environment) with IGCAR Kalpakkam. He has published several papers in journals and conferences (**SAE World Congress**, FISITA) including book chapters in his research area. He has been a reviewer for SAE Technical papers, journals like Surface and Coatings Technology, Surface Engineering, Journal of Nuclear Fusion Engineering.

Dr. R. Rajendran is a recipient of **2019 Excellence in Engineering Education and 2011 Ralph Teetor Education award** from SAE International for his outstanding contributions in teaching, research and Student activities. He has received **FISITA Travelling Fellowship in 2006 from SAEJAPAN** to participate in technical tours to Toyota, Honda, Yamaha, JARI, Nissan Oppama, NTSEL at FISITA World Congress 2006 at Yokohama, Japan.